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Effects of machine parameters on surface roughness using response surface method in drilling process

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Abstract

The optimization of surface integrity in drilling process using response surface method (RSM) is presented. This paper investigates the effects of drilling parameter such as spindle speed, feed rate and drill diameter on the surface roughness and surface texture of drilled hole by applying RSM. There are three factors (spindle speed, feed rate and drill diameter) under investigation, therefore, by applying RSM there will be 20 experimental observations. The minimum surface roughness measured for the hole was 1.06 µm at combination of 2000 rpm spindle speed, 78 mm/min feed rate and 2.5 mm drill diameter. While the maximum surface roughness of 2.59 µm was measured at the combination of 250 rpm spindle speed, 153 mm/min feed rate and 3.5 mm drill diameter. One factor plot analysis found that the most significant parameter was spindle speed followed by drill diameter and feed rate. Thus, surface roughness decreased when increasing the spindle speed, feed rate and drill diameter. There were interactions between all the parameter of spindle speed, feed rate and drill diameter in drilling process under investigation.

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Keywords: Drilling process; Machining parameters; Surface roughness; Response surface method

Nomenclature

µm	micrometre
mm	millimetre
rpm	revolution per minute
mm/min	millimetre per minute
GRFP	glass-fibre reinforced plastic

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1. Introduction

Drilling is one of the most important machining processes. Approximately 75% of all metal cutting process involves drilling operation [1]. In automotive engine production, costing of drilling hole is among the highest [2]. Therefore, surface integrity is an important parameter in manufacturing engineering. It is because, surface integrity can influence the performance of final parts and it's quality [3]. In order to study the relationship between drilling process parameters and surface integrity, a systematically approach, the design of experiments (DOE); response surface method (RSM) can be used effectively. Kasim et al. [4] demonstrated RSM able to predict surface roughness value with 3% error.

Since drilling process is one from the most important process in industry, several researchers were studied in order to optimize the quality in this process. Mohan et al. [5] investigated the effect of cutting speed, feed rate, drill size and sample thickness on cutting force and torque when drilling of glass fibre polyester reinforced composites. Khashaba et al. [6] presented a story of the influence of drilling parameters (cutting speed and feed rate) on the required cutting forces, torques and delamination that occurs at drill entrance and exit in drilling composites with different fibre volume fractions. Tsao and Hocheng [7] investigated a prediction and evaluation of delamination factor in use of twist drill, candle stick drill and saw drill. The objective of their study was to establish a correlation between feed rate, spindle speed and drill diameter. Rao, et al. [8] presented a comprehensive study of delamination in use of various drill types, three different feed rate and spindle speeds. Kilickap [9] investigated the influence of the cutting parameters, such as cutting speed and feed rate, and point angle on delamination produced when drilling a glass-fibre reinforced plastic (GFRP) composite. Further, Onwobolo [10] investigated about the correlating the interactions of some drilling control parameters such as speed, feed rate and drill diameter and their effects on some responses such as axial force and torque acting on the cutting tool during drilling by means of response surface method.

In this study, the effects of parameters such as spindle speed, feed rate and drill diameter on the surface integrity were investigated in term of surface roughness and appearance observation of hole by using a mathematical and statistical approach, RSM and one factor plot analysis.

2. Experimental

2.1. Materials

Aluminium alloy was chosen as the work piece material for the test sample. There were combinations of two pieces of work piece. The dimension of each work piece was 150 mm x 50 mm x 9 mm. The cutting tool used was twist drill high speed steel (HSS). The diameters of the drill were 1.5 mm, 2.5 mm, 3.5 mm, 5 mm and 5.5 mm.

2.2. Experimental matrix

Three factors were selected for this experiment. There are spindle speed, feed rate and drill diameter with two levels as shown in Table 1. Then, the process control parameters and their limit was substitute into Microsoft Design Expert version 6.0. By applying RSM, the planning matrix will contain the value exceeds the (-1) or (+1) range to allow estimation of curvature. The lower limit for low (-1) was added for spindle speed (250 rpm), feed rate (27 mm/min) and drill diameter (1.5mm). While the upper limit for (+1) was added for spindle speed (2590 rpm), feed rate (279 mm/min) and drill diameter (5.5mm).

Table 1. Process control parameters and limitation

Factors	Parameters	Limit	
		-1	1
A	Spindle Speed (rpm)	270	2000
B	Feed Rate (mm/min)	78	228
C	Drill diameter (mm)	2.5	5

2.3. Sample preparation

In this project, the drilling process was carried out by using Mazak 630-5x CNC vertical milling machine. Besides that, portable surface roughness tester, Mettle Toledo, and optical microscope were used to measure and analyze the result. Fig 1 shows the sample of the work piece prepared by milling machine. The raw material size was 610mm x 55mm x 10mm. Then, the raw material was cut into 4 pieces by using band saw machine. Each part was cut into 151mm x 55mm x 10mm. Then, each work piece was cut facing process to size 150mm x 50mm x 9mm. The purpose of cut facing process to make sure the surface was smooth. Smooth surface allows the work piece attach properly and fixed by cap screw neatly. The work pieces were fixed by M6 cap screw and inserted by guide pin for reference purposes.

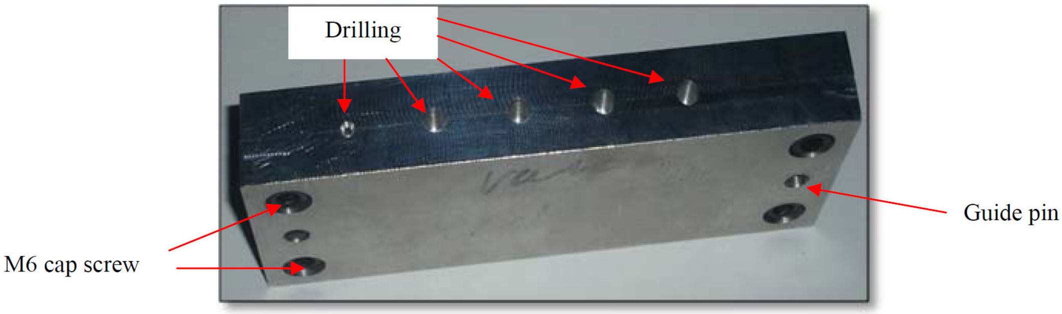

Fig. 1. Drilling sample for drilling process

3. Result and discussion

Experimental result of surface roughness for drilling process is shown in Table 2. From the result, the minimum of surface roughness is 1.06μm and the maximum is 2.59μm. All run samples were finish drilling process; accept for the sample number 3 due to drill fracture, and then the surface roughness cannot be measure. This because of the tool was broken. It is shown that, the combination between spindle speed, feed rate and drill diameter for sample number 3 is inappropriate.

Table 2. Experimental result for surface roughness for drilling process

No.	Factor A Spindle Speed (N) (rpm)	Factor B Feed Rate (f) (mm/min)	Factor C Drill Diameter (d) (mm)	Surface Roughness (μm)
1	270	78	2.5	1.86
2	2000	78	2.5	1.06
3	270	228	2.5	Cannot measure (drill broken)
4	2000	228	2.5	1.24
5	270	78	5	1.42
6	2000	78	5	1.62
7	270	228	5	1.17
8	2000	228	5	1.31
9	250	153	3.5	2.59
10	2590	153	3.5	1.74
11	1135	27	3.5	2.56
12	1135	279	3.5	2.33
13	1135	153	1.5	1.97
14	1135	153	5.5	1.19
15	1135	153	3.5	1.82
16	1135	153	3.5	1.8
17	1135	153	3.5	1.79
18	1135	153	3.5	1.8
19	1135	153	3.5	1.83
20	1135	153	3.5	1.73

Equation 1 shows the mathematical relationship for correlating the surface roughness considering output responses of drilling parameters, i.e. spindle speed, feed rate and spindle speed. The mathematical model was obtained from using design expert software. The differential between minimum and maximum of experimental and calculated is 0% and 29% respectively. Further, the average error between experimental and calculated surface roughness is 7.2% as shown in Fig 2.

$$\begin{aligned}\text{Surface Roughness} = &-10.193+1.68E\text{-}04 * A+0.09198 * B+6.34308 * C+2.53E\text{-}07 * A^2 \\ &+2.93E\text{-}05 * B^2-0.771 * C^2-2.13E\text{-}05 * A * B-1.10E\text{-}04 * A * C \\ &-0.042075 * B * C+4.31E\text{-}03 * B * C^2+4.21E\text{-}06 * A * B * C\end{aligned} \quad (1)$$

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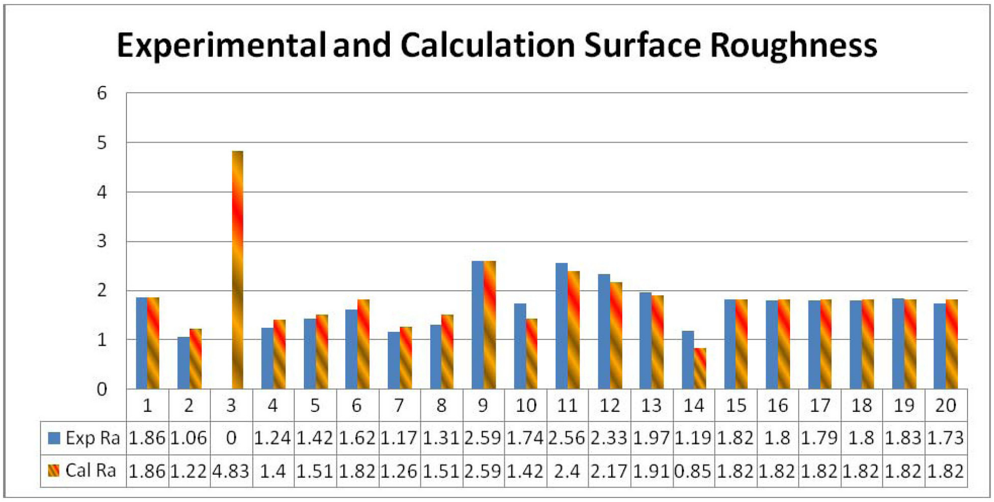

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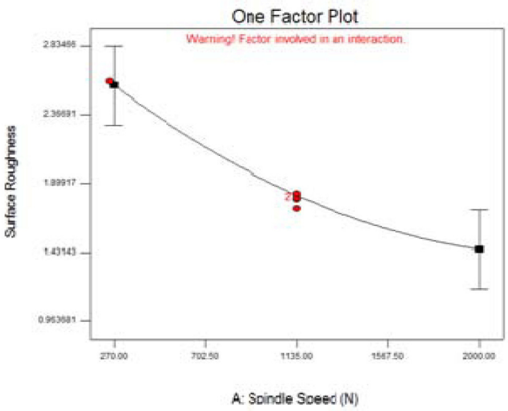
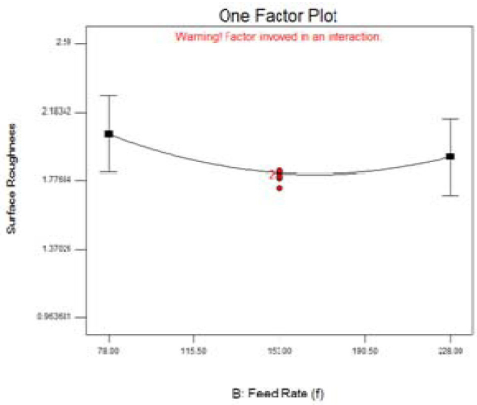
Fig. 2. Graph for experimental and calculated of surface roughness

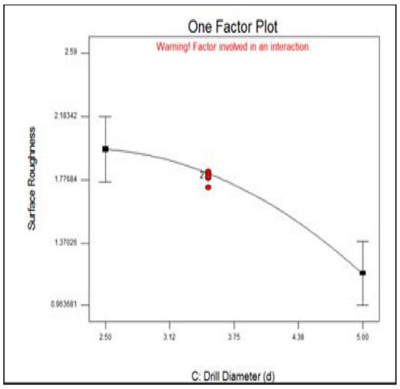
Fig 3(a), (b) and (c) show the one factor plot for spindle speed, feed rate and drill diameter towards surface roughness. However, there are interactions among each of parameters. From the graph, the most significant parameter is spindle speed followed by drill diameter and feed rate. For one factor plot, the value of surface roughness is decreased when the spindle speed, feed rate and drill diameter increase. It is shown that, if the only parameters that manipulated, the surface roughness is inversely proportional with the spindle speed, feed rate and drill diameter. #



(a)



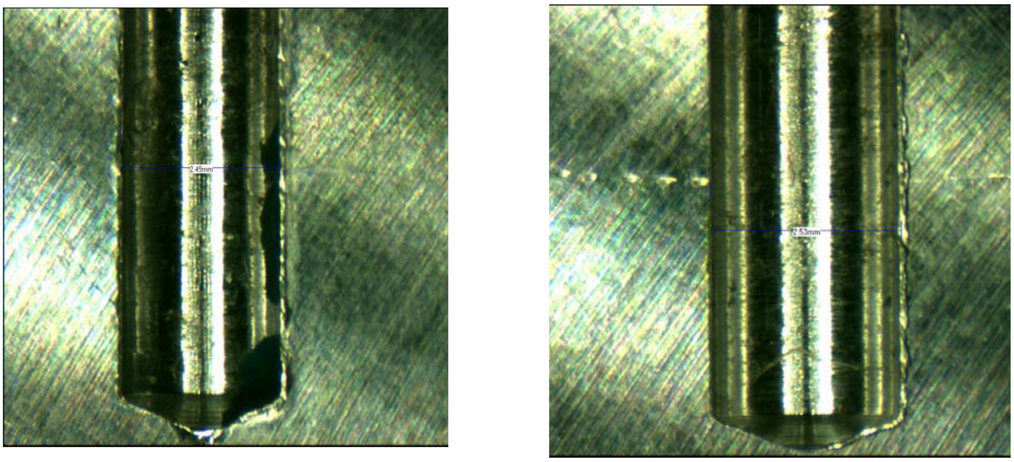
(b)



(c)

Fig. 3. One factor plot for (a) spindle speed, (b) feed rate and (c) drill diameter

Higher spindle speed helps remove excess heat rapidly and also ejects the chips produced during drilling process. Figure 4(a) and 4(b) show the holes observation for sample number 1 and 2 respectively. Sample number 1 shows in the figure for low spindle speed and sample number 2 shows the high spindle speed.



(a) (b)

Fig. 4. (a) Sample number 1 for low spindle speed and (b) Sample number 2 for high spindle speed.

Figure 5 shows the sample for number 3. Sample number 3 is the combination of spindle speed at 270 rpm, feed rate 228 mm/min and drill diameter 2.5. The spindle speed is low and the feed rate is high. As a result, the higher feed rate produces excessive chip loading. The excessive chip loading was contributed to the clog and causes the cutting edges to fracture. Therefore, the drill for samples number 3 was broken.

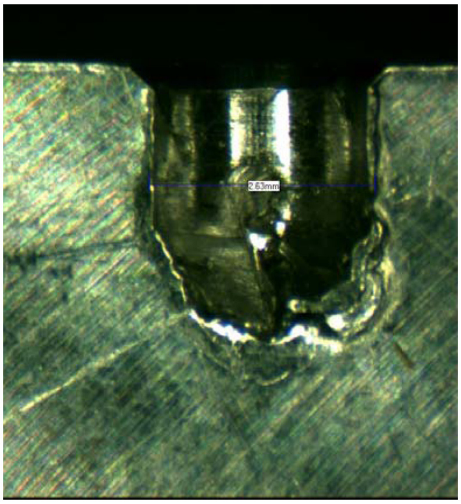


Fig. 5. Broken tool for sample number 3.

4. Conclusion

In this study, the effect of drilling parameters on surface roughness of drilling hole using RSM was studied. From the result, the minimum and maximum surface roughness was 1.06 µm and 2.59 µm respectively. However, for the sample number 3, the surface roughness cannot be measured. This was due to the broken tool. It could be concluded that the appropriate combination of spindle speed, feed rate and drill diameter were very important for drilling process. The optimization performed found that the parameters that affects surface roughness was spindle speed, followed by drill diameter and feed rate.

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